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Personal and demographic factors and change of subjective indoor air quality reported by school children in relation to exposure at Swedish schools: A 2-year longitudinal study

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HIGHLIGHTS

- SIAQ among pupils was related to exposure in classrooms and personal factors.
- Better ventilation and illumination were associated with improved SIAQ among pupils.
- Higher levels of VOC and CO_2 were associated with impaired SIAQ among pupils.

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ABSTRACT

This paper studies changes in subjective indoor air quality (SIAQ) among school children and relates these data to repeated exposure measurements during a two-year follow-up period. Data on SIAQ and demographic information were gathered by a questionnaire sent to 1476 primary and secondary school pupils in 39 randomly selected schools at baseline and after two years (follow-up). Exposure measurements were applied after questionnaire data were collected at baseline and follow-up in approximately 100 classrooms. The arithmetic mean values for baseline and follow-up were: for indoor air temperature 23.6 °C and 21.8 °C and for outdoor air flow rate 5.4 L/s and 7.9 L/s. Older children, those with atopy at baseline, and those in larger schools reported impaired SIAQ during follow-up. Installation of new ventilation systems, higher personal air flow rate and air exchange rate, and better illumination were associated with improved SIAQ. Higher CO_2 levels were associated with impaired SIAQ. In conclusion, sufficient ventilation and illumination in classrooms are essential for the perception of good indoor air quality.

1. Introduction

Indoor environment may affect different types of illnesses in children (Annesi-Maesano et al., 2012; Bornehag et al., 2004; Wålinder et al., 1998). School environment is an important indoor environment for children. In Sweden, a majority of children attend public elementary and secondary schools from ages 7 to 16. Many classrooms are not adequately ventilated (Daisey et al., 2003), with ventilation flows below the ASHRAE ventilation standard (ASHRAE, 1999). Previous studies have shown that schools can be contaminated by various indoor pollutants, such as molds, bacteria, allergens, particles, volatile organic compounds, and formaldehyde (Norbäck et al., 1990; Perzanowski et al., 1999; Salo et al., 2009; Smedje et al., 1997). Studies in different countries have shown that poor indoor air quality in schools can be associated with children's asthma, allergic diseases, and other respiratory infections (Annesi-Maesano et al., 2012, 2013; Kim et al., 2005, 2011; Wålinder et al., 1998; Zhao et al., 2008), and that exposures or insufficient ventilation might also have adverse effects on children's academic performance (Annesi-Maesano et al., 2013; Mohai et al., 2011; Mendell and Heath, 2005; Shaughnessy et al., 2006).

Complaints about poor indoor air quality can be an early indication of a problem in the indoor environment. Former studies have shown that complaints concerning poor indoor air quality are very common (Mendell, 1993; Sundell et al., 1994; Skov et al., 1987). Epidemiological studies on the association between subjective air quality and sick building syndrome symptoms have been published, mainly in office workers (Kolarik et al., 2009; Sundell et al., 1994; Wargocki et al., 2000, 2002). There are some experimental exposure chamber studies relating subjective air quality to single exposure such as temperature (Reinikainen

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et al., 1992), air humidity (Andersen et al., 1974), ventilation (Wargocki et al., 2000), or a mixture of volatile organic compounds (VOCs) (Broder et al., 1993; Hudnell et al., 1992; Molhave et al., 1986). Some recent studies have shown that a higher ventilation rate, using variable air flow instead of constant air flow and a displacement ventilation system instead of a mixing ventilation system, were associated with students' positive perception of indoor air quality (Norbäck et al., 2011, 2013; Norbäck and Nordström, 2008). However, there are few epidemiological studies on subjective indoor air quality (SIAQ) in relation to measured indoor exposures.

A few studies about exposure factors related to subjective indoor air quality in schools, reported by school personnel, are available. One study found that school personnel's perception of temperature, air dryness, and dusty air were associated with measured indoor air quality in classrooms (relative air humidity and VOC) (Norbäck, 1995). Another study conducted in a school showed that school personnel's perceived air quality was negatively associated with levels of VOC, mold, bacteria, and respirable dust in classroom air, and that exposure to indoor pollutants affected this perception even at the low concentrations normally found indoors in non-industrial buildings (Smedje et al., 1997). We found no longitudinal studies about measured air quality or meteorological factors in schools in relation to subjective indoor air quality reported by pupils.

This paper presents results concerning changes in subjective indoor air quality (SIAQ) perceived by pupils in relation to degree of exposure. We have previously published two studies on the effects of ventilation improvements, one on asthma and asthmatic symptoms (Smedje and Norbäck, 2000) and one on SIAQ among teachers and staff in relation to exposure in a school environment (Smedje et al., 1997). The current study was to investigate changes in SIAQ reported by pupils during a two-year follow-up period in relation to personal and demographic.

The following hypotheses were tested: regarding personal and demographic factors: changes in SIAQ reported by pupils are related to gender, age, atopy, size of town, and size of the school; regarding the school environment: changes in SIAQ are related to levels of carbon dioxide, outdoor air flow rate, air exchange rate, room temperature, relative air humidity, illumination, daylight factor, and levels of formaldehyde, bacteria, molds, particles of a size below 5 μm (PM_5), VOC, signs of dampness and mold, installation of a new ventilation system, and redecoration, including painting and installation of new floor materials.

2. Material and methods

2.1. Ethics statement

We sent an information letter to the parents' and children's home addresses, along with the questionnaire, stating that if they answered and returned the questionnaire, they were thereby giving their informed consent. The nature and possible consequences of the study were explained to the subjects before the study began. The questionnaire study and the exposure measurements in the schools had been granted permission by the principal of each school and the head teacher of each class involved in the study. The study protocol and the consent procedure were approved by the Ethical Committee of the Medical Faculty of Uppsala University, which did not require a written consent since the study did not include any clinical tests.

2.2. Study population

In Sweden, there are nine grades in the compulsory school system. A total of 130 schools of this range were identified in the county of Uppsala, of which 40 were randomly selected for our study and 39 agreed to participate. They consisted of 28 primary schools (grades 1–6) and 11 secondary schools (grades 7–9). For each primary school, we randomly selected one class in each of the first and fourth grades. Since the number of secondary schools was lower than the number of primary schools, we randomly selected three classes in the 7th grade of the secondary schools, with the exception of one school, which only had three classes in that grade. This gave a total of 615 pupils in the first grade (approximately 7 years of age), 657 in the fourth grade (approximately 10 years of age), and 762 in the seventh grade (approximately 13 years of age) being invited to participate, with a grand total of 2034 pupils.

At baseline, a self-administered questionnaire that had also been used in previous Swedish, Chinese, and Korean school studies (Kim et al., 2007; Mi et al., 2006; Smedje et al., 1997; Zhao et al., 2006) was mailed to the home addresses of these 2034 pupils in January and February of 1993, and 1732 (85%) completed forms were returned. After two years (follow-up), the same questionnaire was sent to the 1598 pupils who responded at baseline and who still attended the same school in December, 1994 and January, 1995 (134 pupils had moved), of which 1476 (92%) answered. Of the 1879 pupils who attended the same school during the entire period, 79% answered the questionnaire both years. In the case of the secondary school pupils, the questionnaire was sent in the name of the pupil, but for pupils aged under 13 it was mailed to the parents. There was a higher percentage of non-responders among the secondary school pupils than among the primary school pupils (response rates were 76% and 81%, respectively).

2.3. Information from the pupils

The self-administered questionnaire, containing questions about age, current smoking, atopy (hay fever, pet allergy, and/or childhood eczema), type of dwelling, size of town (number of inhabitants), and size of school (number of employees), was sent to each of the pupils. The question about smoking was only asked of the oldest children, who were in the 7th grade at baseline. There was one question on subjective indoor air quality (SIAQ), namely: “On average, how do you perceive the indoor air quality (IAQ) in your classroom?” The question had four alternative responses: very poor (0), fairly poor (1), fairly good (2), and very good (3). The difference between the SIAQ at baseline and at follow-up was used as an independent variable in this study, a positive value indicating a perception of improved indoor air quality.

2.4. Assessment of exposure

Exposure measurements were performed in the schools using identical methods at baseline (March–May 1993) and follow-up (January–March 1995). The measurements were performed during normal conditions, with a full class and windows opened as much as usual. Classroom temperature, relative air humidity, concentrations of CO_2, PM_5, formaldehyde, other VOCs, mold and bacteria, air exchange rate, and illumination were measured. In the primary schools, each class has its own classroom, where they spent most of their time, so, for this group, the measurements were taken in the classrooms only. In the secondary schools, pupils go to different classrooms during the day, depending on the subject, so we choose 2–5 classrooms that were representative of the school buildings. During the follow-up, some classes had changed rooms, in which case the repeated measurements were made in the new classroom. At baseline, 98 classrooms were investigated; at follow-up, this number was 101, while 51 of the classrooms were visited at both baseline and follow-up. The measurement data at baseline or follow-up were addressed to all pupils in the particular classroom.

Room temperature and relative air humidity were recorded using an Assmann psychrometer. Carbon dioxide (CO_2) and PM_5 were measured as average values during 15-min periods using direct-reading instruments (Riken RI 411-A and Sibata P-5H2, respectively). The Riken was calibrated at our department, whereas the Sibata was calibrated at the factory (Sibata Scientific Technology, Tokyo, Japan). Temperature, relative air humidity, CO_2, and PM_5 were measured twice in each classroom, at the end of a lesson. Formaldehyde was measured using glass fiber filters impregnated with 2,4-dinitro-phenylhydrazine, at a sampling rate of 0.2 L/min, for 4 h (Andersson et al., 1981). The filters were analyzed